What is functional programming?

“Functional programming” can mean a few different things:

1. Avoiding mutation in most/all cases (done and ongoing)
2. Using functions as values (this unit)

... 

- Style encouraging recursion and recursive data structures
- Style closer to mathematical definitions
- Programming idioms using laziness (later topic, briefly)
- Anything not OOP or C? (not a good definition)

Not sure a definition of “functional language” exists beyond “makes functional programming easy / the default / required”
- No clear yes/no for a particular language

First-class functions

- First-class functions: Can use them wherever we use values
  - Functions are values too
  - Arguments, results, parts of tuples, bound to variables, carried by datatype constructors or exceptions, ...

```
fun double x = 2*x
fun incr x = x+1
val a_tuple = (double, incr, double(incr 7))
```

- Most common use is as an argument / result of another function
  - Other function is called a higher-order function
  - Powerful way to factor out common functionality

Function Closures

- Function closure: Functions can use bindings from outside the function definition (in scope where function is defined)
  - Makes first-class functions much more powerful
  - Will get to this feature in a bit, after simpler examples

- Distinction between terms first-class functions and function closures is not universally understood
  - Important conceptual distinction even if terms get muddled

Onward

The next week:
- How to use first-class functions and closures
- The precise semantics
- Multiple powerful idioms

Functions as arguments

- We can pass one function as an argument to another function
  - Not a new feature, just never thought to do it before

```
fun f (g, ..) = ... g (...) ...
fun h1 .. = ...
fun h2 .. = ...
    f(h1, ..) .. f(h2, ..) ...
```

- Elegant strategy for factoring out common code
  - Replace N similar functions with calls to 1 function where you pass in N different (short) functions as arguments

[See the code file for this lecture]
**Example**

Can reuse \( n \times \) rather than defining many similar functions

– Computes \( f(f(\ldots f(x))) \) where number of calls is \( n \)

```haskell
fun n_times (f,n,x) = 
  if n=0
  then x
  else f (n_times(f,n-1,x))
```

```haskell
fun double x = x + x
fun increment x = x + 1
val x1 = n_times(double,4,7)
val x2 = n_times(increment,4,7)
val x3 = n_times(tl,2,[4,8,12,16])
```

```haskell
fun double_n_times (n,x) = n_times(double,n,x)
fun nth_tail (n,x) = n_times(tl,n,x)
```

**Relation to types**

• Higher-order functions are often so “generic” and “reusable” that they have polymorphic types, i.e., types with type variables

• But there are higher-order functions that are not polymorphic

• And there are non-higher-order (first-order) functions that are polymorphic

• Always a good idea to understand the type of a function, especially a higher-order function

**Types for example**

```haskell
fun n_times (f,n,x) = 
  if n=0
  then x
  else f (n_times(f,n-1,x))
```

```haskell
• val n_times : ('a -> 'a) * int * 'a -> 'a
  – Simpler but less useful: (int -> int) * int * int -> int
  • Two of our examples instantiated 'a with int
  • One of our examples instantiated 'a with int list
  • This polymorphism makes n_times more useful
  • Type is inferred based on how arguments are used (later lecture)
    – Describes which types must be exactly something (e.g., int) and which can be anything but the same (e.g., 'a)
```

**Polymorphism and higher-order functions**

• Many higher-order functions are polymorphic because they are so reusable that some types, “can be anything”

• But some polymorphic functions are not higher-order
  – Example: len : 'a list -> int

• And some higher-order functions are not polymorphic
  – Example: times_until_0 : (int->int)*int->int

```haskell
fun times_until_zero (f,x) = 
  if x=0 then 0 else 1 + times_until_zero(f, f x)
```

Note: Would be better with tail-recursion

**Toward anonymous functions**

• Definitions unnecessarily at top-level are still poor style:

```haskell
fun trip x = 3*x
fun triple_n_times (f,x) = n_times(trip,n,x)
```

• So this is better (but not the best):

```haskell
fun triple_n_times (f,x) = 
  let fun trip y = 3*y
  in
    n_times(trip,n,x)
  end
```

• And this is even smaller scope
  – It makes sense but looks weird (poor style; see next slide)

```haskell
fun triple_n_times (f,x) = 
  n_times(let fun trip y = 3*y in trip end, n, x)
```

**Anonymous functions**

• This does not work: A function binding is not an expression

```haskell
fun triple_n_times (f,x) = 
  n_times((fun trip y = 3*y), n, x)
```

• This is the best way we were building up to: an expression form for anonymous functions

```haskell
fun triple_n_times (f,x) = 
  n_times((fn y => 3*y), n, x)
```

– Like all expression forms, can appear anywhere

– Syntax:

  • fn not fun
  • => not =

  • no function name, just an argument pattern
Using anonymous functions

- Most common use: Argument to a higher-order function
  - Don’t need a name just to pass a function
- But: Cannot use an anonymous function for a recursive function
  - Because there is no name for making recursive calls
  - If not for recursion, `fun` bindings would be syntactic sugar for `val` bindings and anonymous functions

```ml
fun triple x = 3*x
val triple = fn y => 3*y
```

A style point

Compare:

```
if x then true else false
```

With:

```
(fn x => f x)
```

So don’t do this:

```
n_times((fn y => tl y),3,xs)
```

When you can do this:

```
n_times(tl,3,xs)
```

Map

```ml
fun map (f,xs) =
  case xs of
  [] => []
  | x::xs' => (f x)::(map(f,xs'))

val map : ('a -> 'b) * 'a list -> 'b list
```

Filter

```ml
fun filter (f,xs) =
  case xs of
  [] => []
  | x::xs' => if f x
  then x::(filter(f,xs'))
  else filter(f,xs')

val filter : ('a -> bool) * 'a list -> 'a list
```

Generalizing

Our examples of first-class functions so far have all:
- Taken one function as an argument to another function
- Processed a number or a list

But first-class functions are useful anywhere for any kind of data
- Can pass several functions as arguments
- Can put functions in data structures (tuples, lists, etc.)
- Can return functions as results
- Can write higher-order functions that traverse your own data structures

Useful whenever you want to abstract over “what to compute with”
- No new language features

Returning functions

- Remember: Functions are first-class values
  - For example, can return them from functions
- Silly example:

  ```ml
  fun double_or_triple f =
    if f 7
    then fn x => 2*x
    else fn x => 3*x
  ```

  Has type `(int -> bool) * (int -> int)

  But the REPL prints `(int -> bool) -> int -> int` because it never prints unnecessary parentheses and `t1 -> t2 -> t3 -> t4` means `t1->(t2->(t3->t4))`
Other data structures

• Higher-order functions are not just for numbers and lists

• They work great for common recursive traversals over your own data structures (datatype bindings) too

• Example of a higher-order predicate:
  – Are all constants in an arithmetic expression even numbers?
  – Use a more general function of type
    \((\text{int} \rightarrow \text{bool}) \times \text{exp} \rightarrow \text{bool}\)
  – And call it with \((\text{fn} \ x \Rightarrow x \mod 2 = 0)\)